The DarkSide-50 Outer Detectors

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(for the DarkSide Collaboration)

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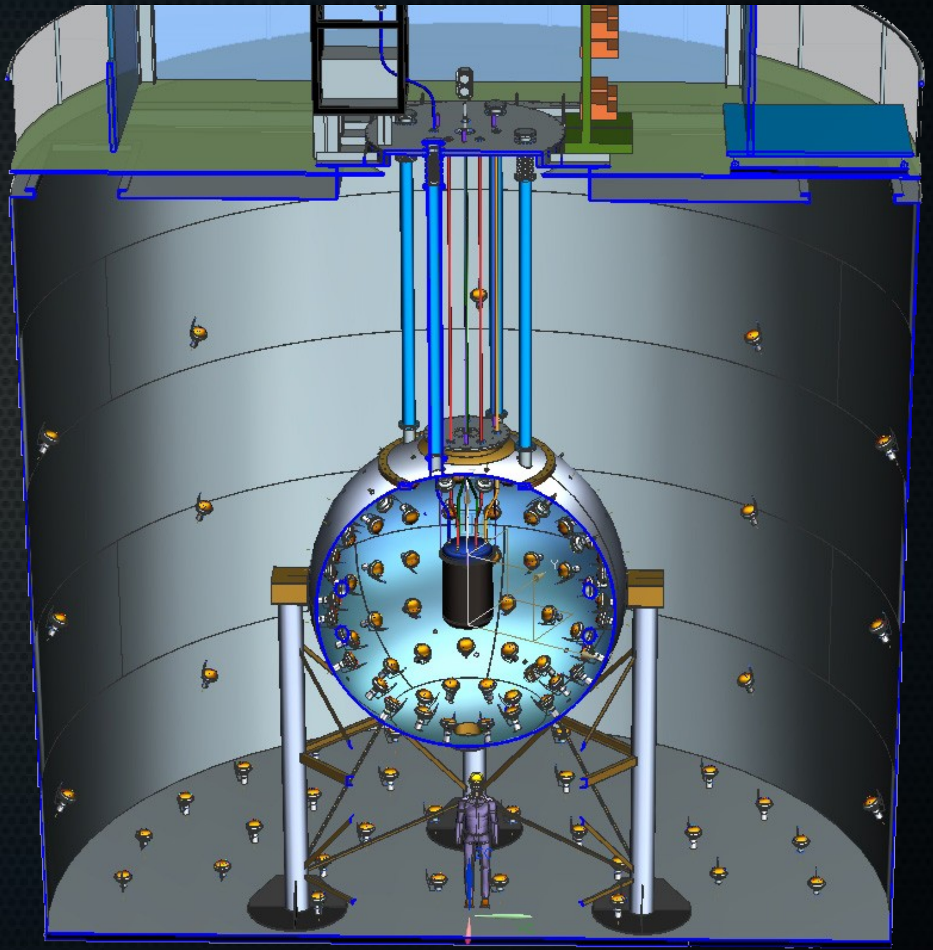
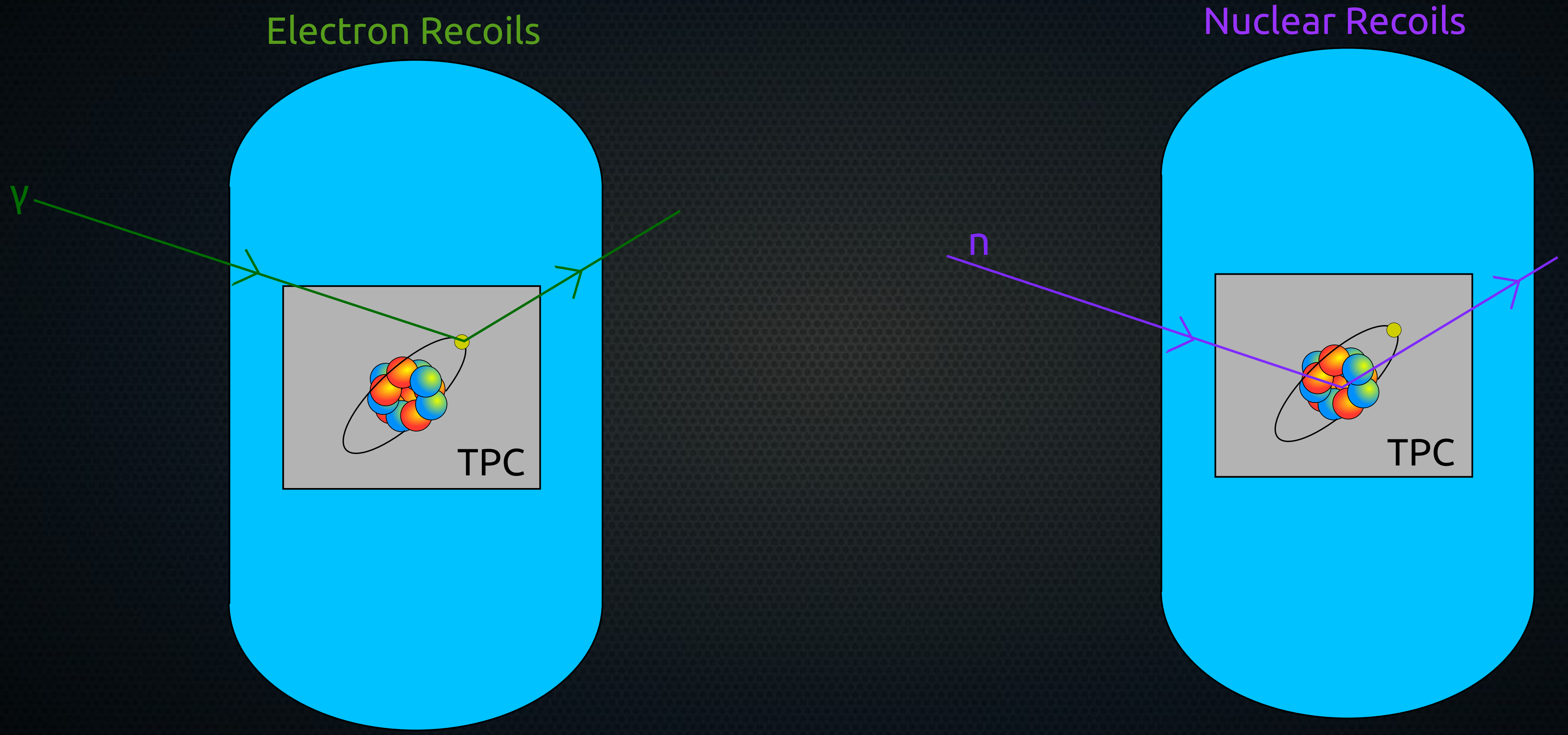
The DarkSide-50 Experiment

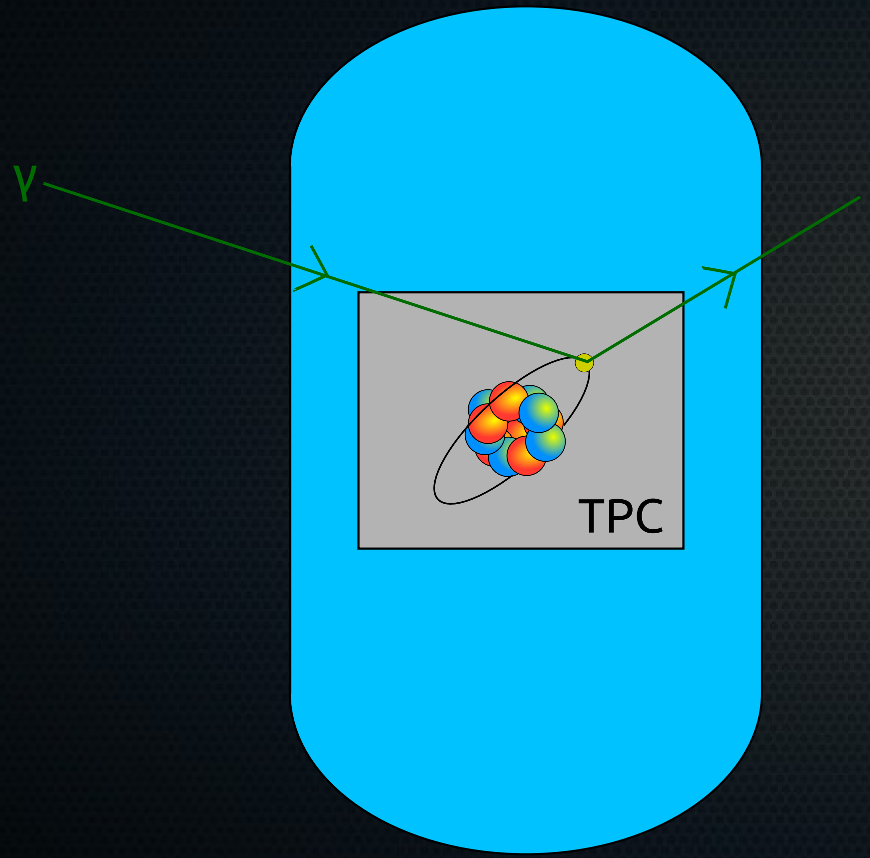
- Located in Hall C of Laboratori Nazionali del Gran Sasso
- WIMP detector, most sensitive in the ~100 GeV region
- 50 kg Liquid Argon Time Projection Chamber (TPC)
- Two part veto system – the Outer Detectors
- See talk by S. Davini for more details



Backgrounds: 2 Types

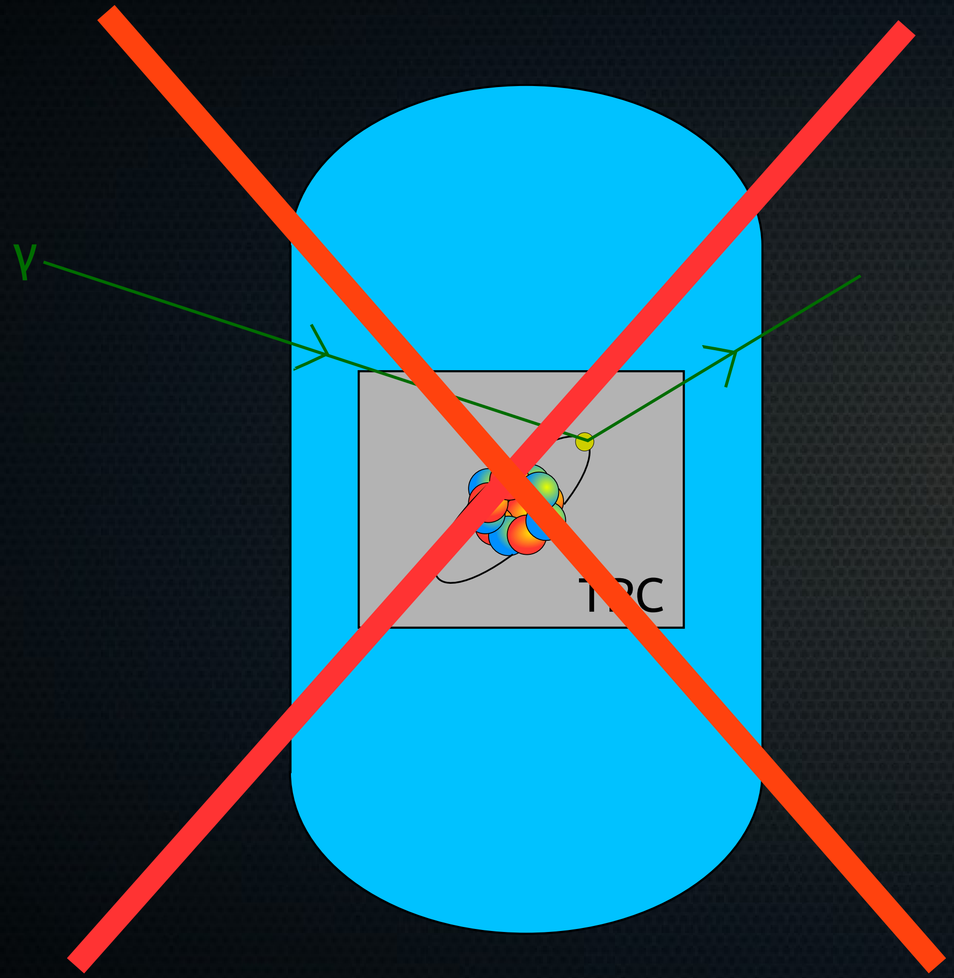


Electron Recoils



- Produced by β decay of ^{39}Ar or from incident γ rays
- Eliminate with pulse shape discrimination in LAr
- Ionization/scintillation signal ratio offers suppression

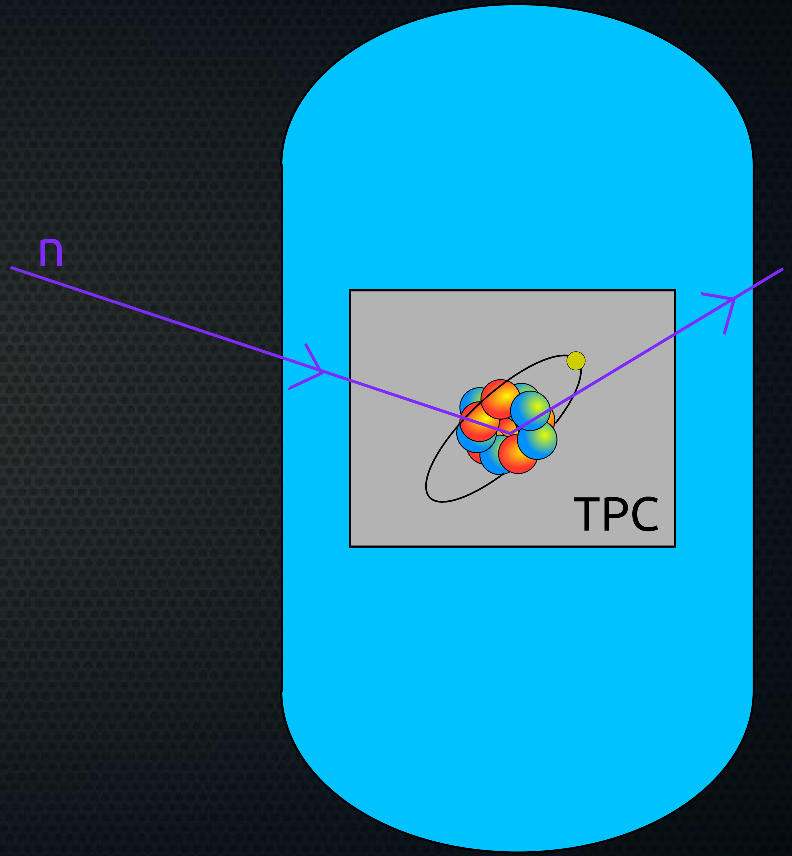
Electron Recoils



- Produced by β decay of ^{39}Ar or from incident γ rays
- Eliminate with pulse shape discrimination in LAr
- Ionization/scintillation signal ratio offers suppression

Nuclear Recoils

- From surface background α decays
  - Eliminated with fiducial cuts
- Neutron scatters
  - Radiogenic (fission and (α,n) reactions)
    - From surrounding environent
    - In detector components
  - Cosmogenic (muon spallation)



Passive Shielding?

- Radiogenic (fission and (α,n) reactions)
  - From surrounding environent
  - In detector components
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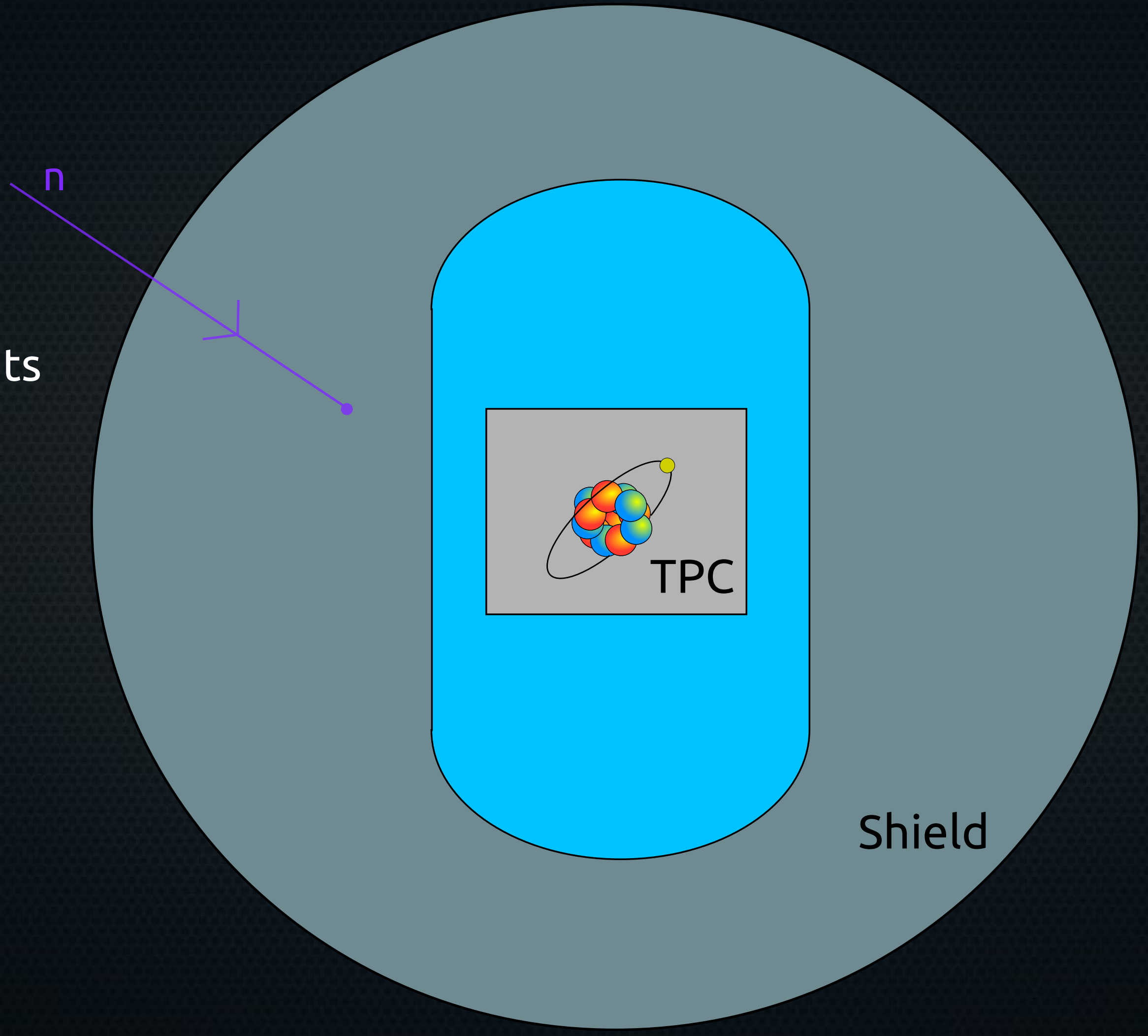

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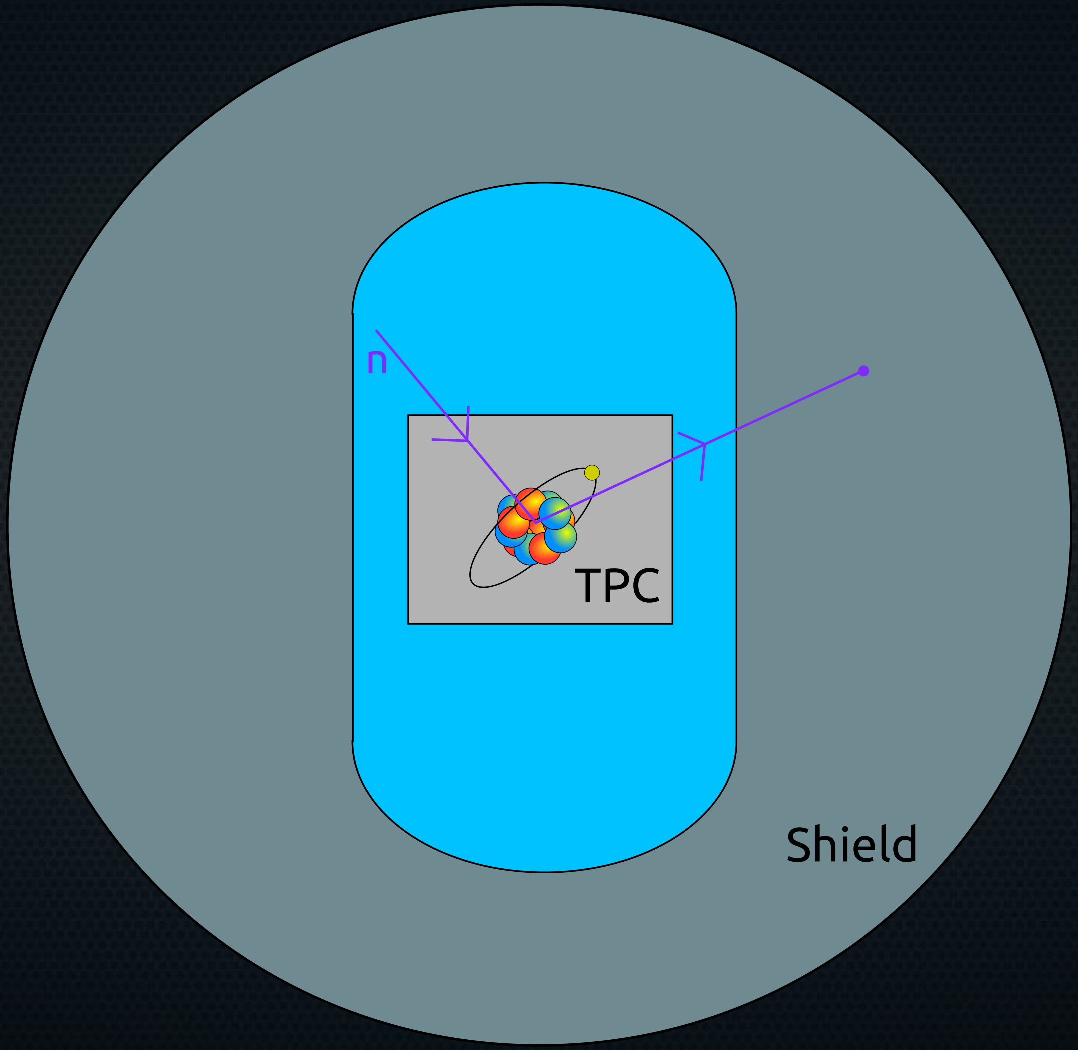

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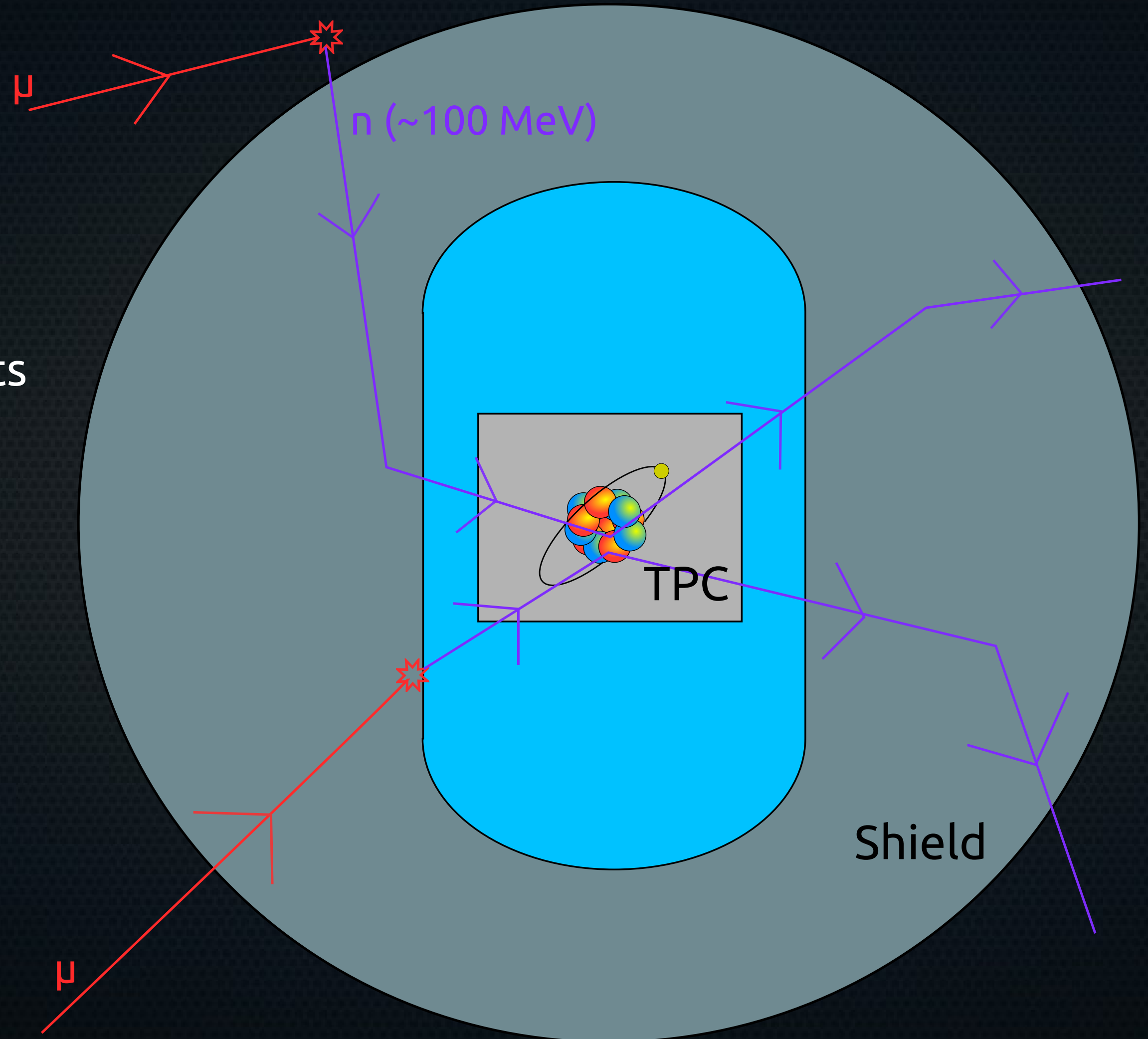
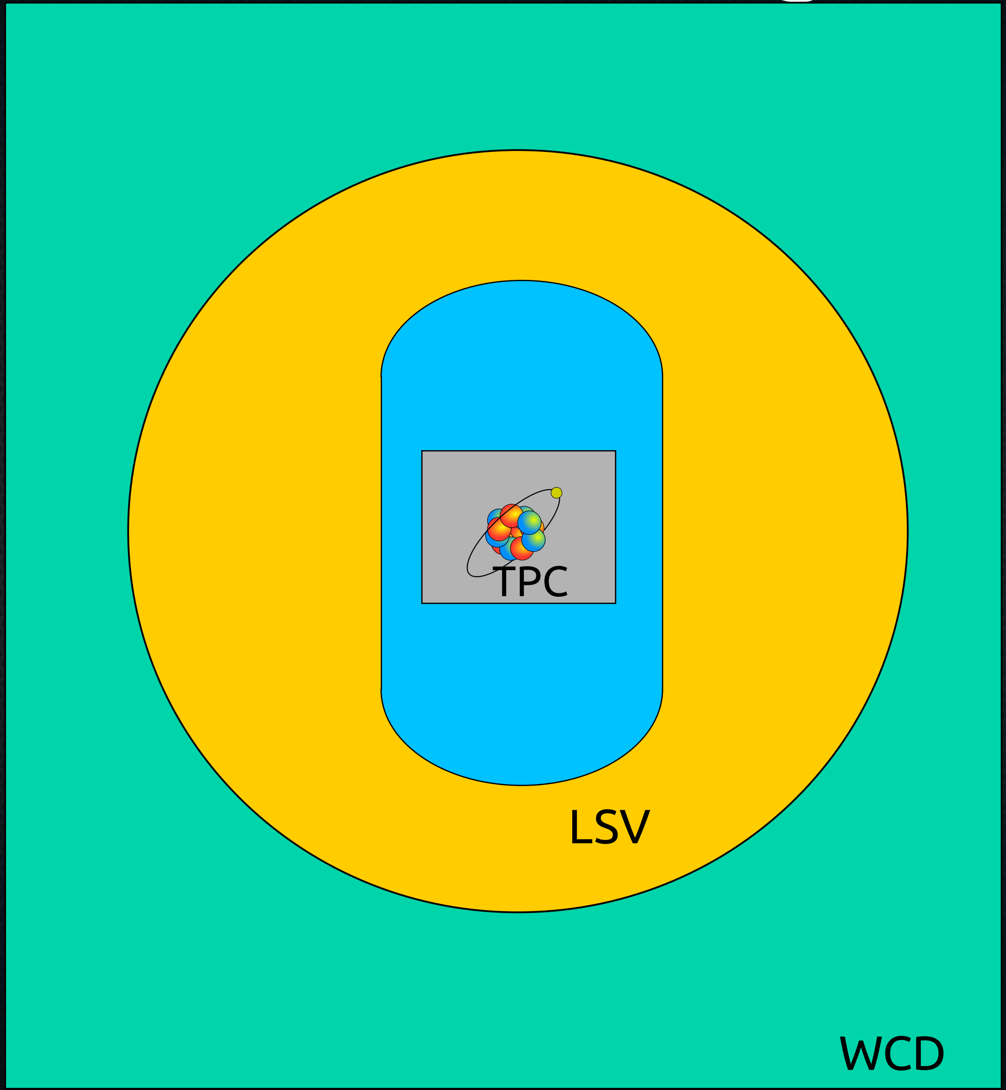


Active Shielding

Water Cherenkov Detector

- Provides shielding to the LSV
- Can detect passing muons that may produce a cosmogenic neutron



Liquid Scintillator Vessel

- Boron-loaded to improve neutron capture cross section
- Detects neutrons and γ rays in coincidence with TPC
- Provides shielding and *vetoing* of backgrounds
- Allows for in situ background measurements

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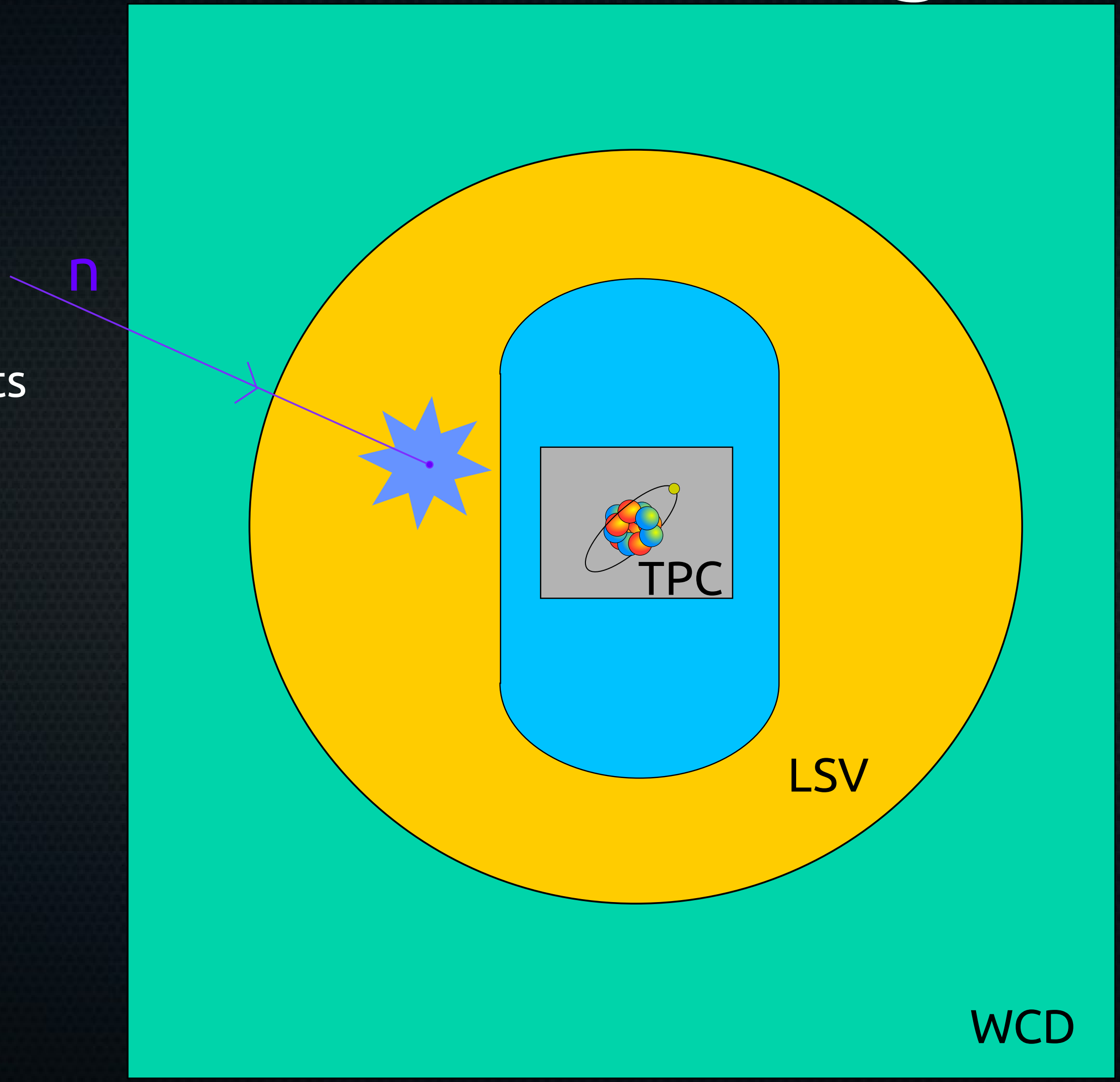

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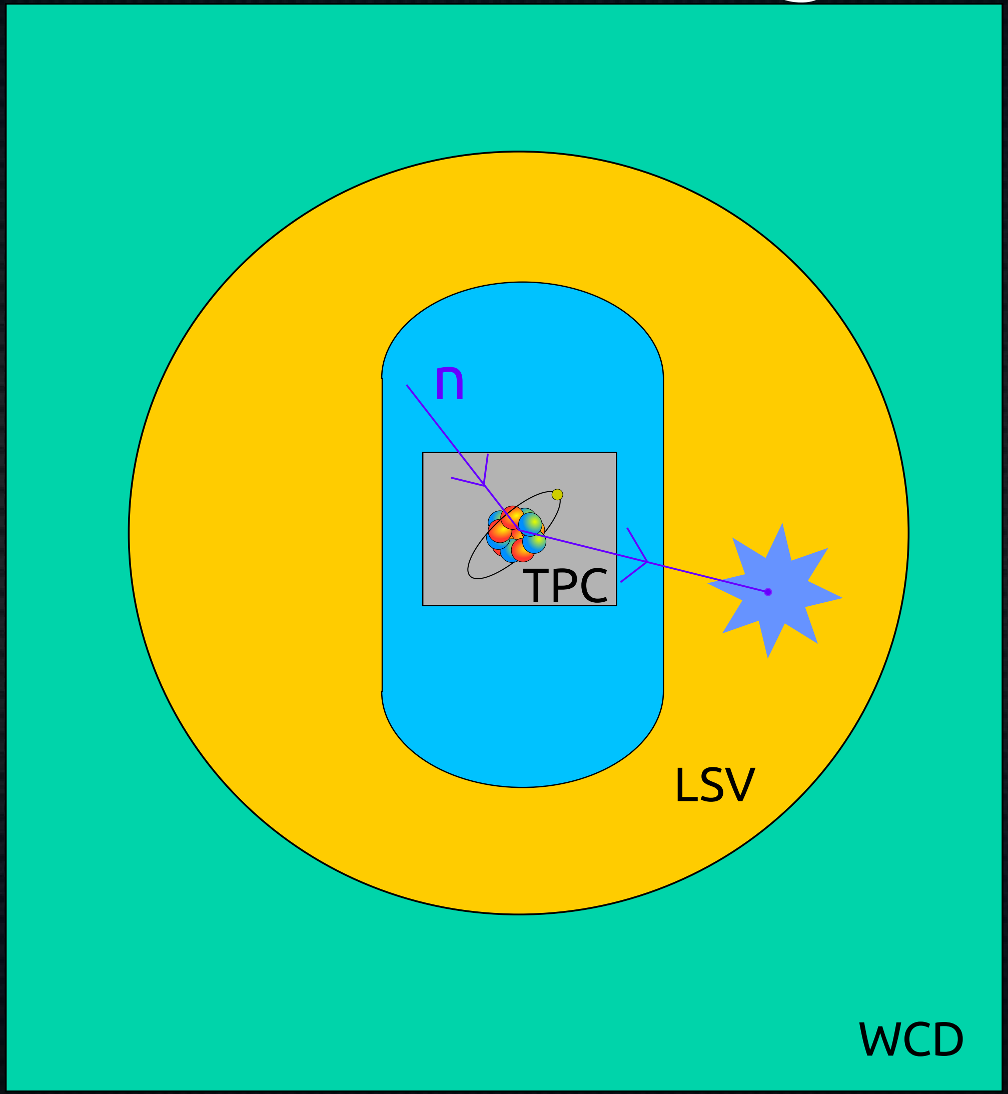

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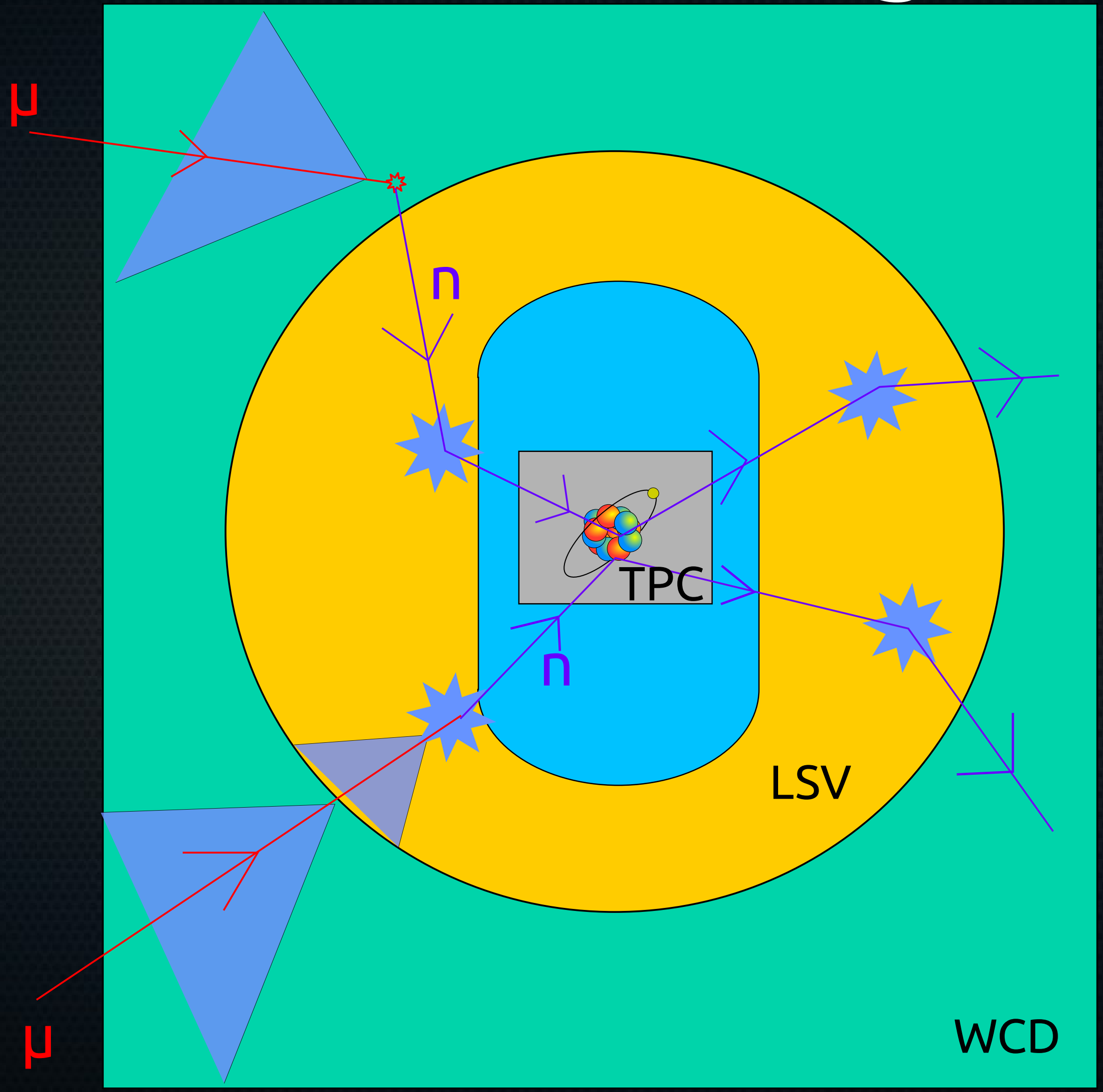
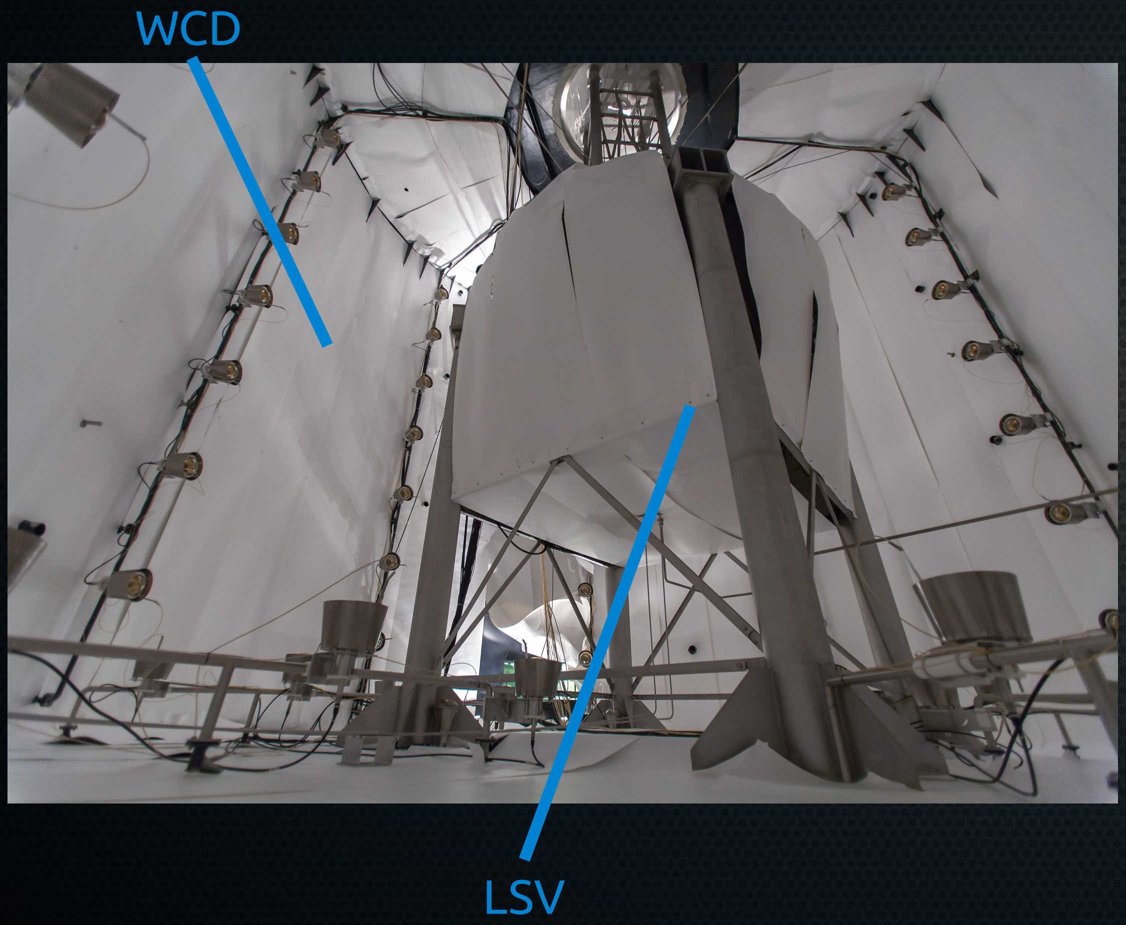
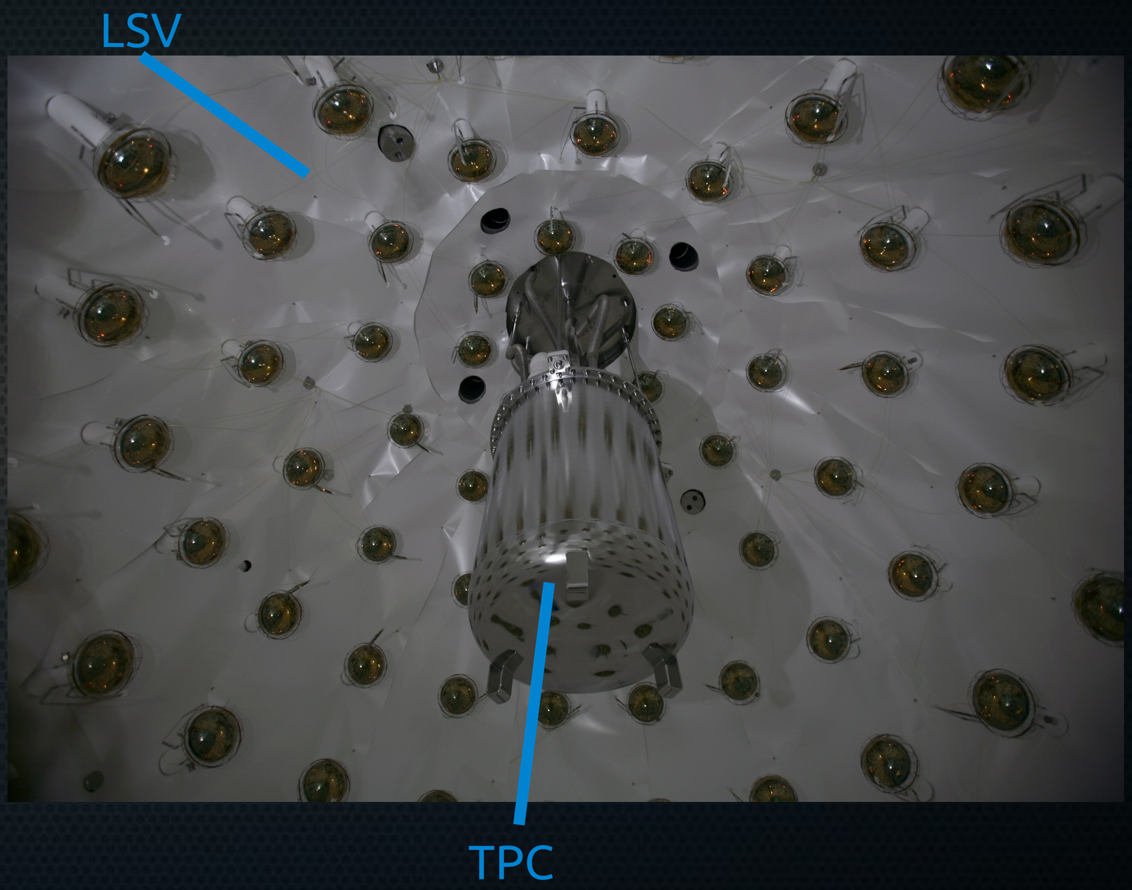


The DarkSide-50 Outer Detectors





The Water Cherenkov Detector

- 11 m diameter x 10 m height cylinder
- Uses the Borexino CTF water tank and PMTs
- 80 PMTs (8“ diameter, ETL9351)
- Tyvek 1082D reflector coating

The Liquid Scintillator Vessel

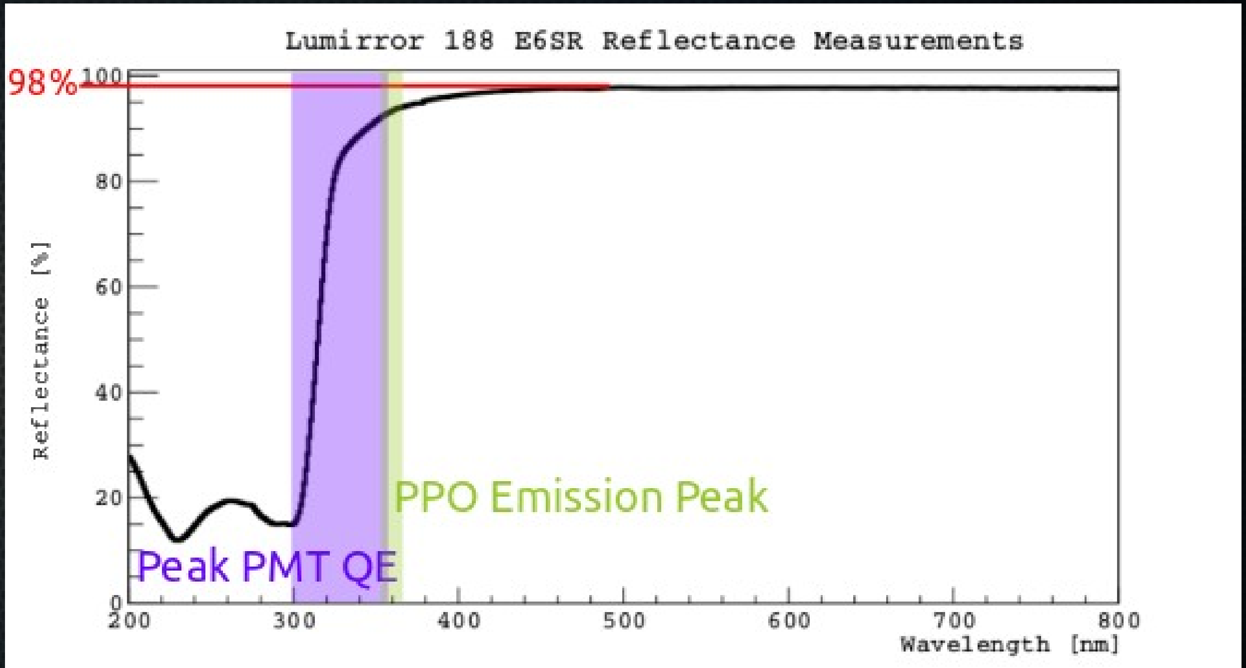
- 4 m diameter sphere
- 110 PMTs (8“ Hamamatsu R5912)
  - 7% coverage
- Lined with Lumirror 188 E6SR reflector
- Pseudocumene (PC) Scintillator
- Trimethyl borate (TMB) for boron-loading
- PPO Wavelength shifter

The DarkSide-50 Outer Detectors: A Prototype

- Before building the DS detectors, tested scintillator cocktails and reflector combinations in a small prototype bell jar
- Found we could build a neutron veto with high efficiency
- See arXiv: 1509.02782

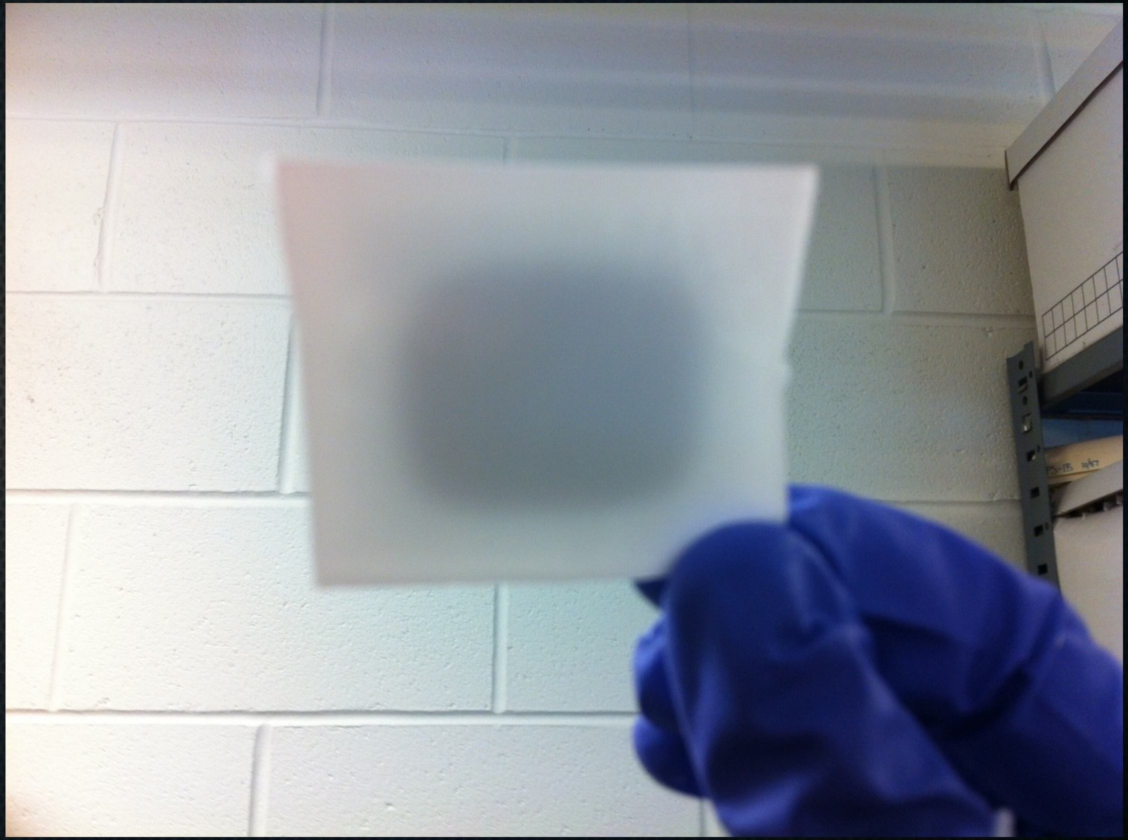
LSV: The Lumirror Reflector

- Very high reflectivity over 350 nm
- Low radioactivity
- Has two protective layers that prevent degradation when submerged in scintillator



LSV: The Lumirror Reflector

- Observed very slow creeping degradation around edges
- ~1 cm per 9 months
- Edges drop to 83% peak reflectance (transparent)
- Bulk remains stable
- Solution: Overlap Lumirror edges when lining LSV



LSV: The Scintillator – A Tale of Two Cocktails

- Phase I
  - Nov 2013 – Jun 2014
  - 50% PC, 50% TMB
  - 2.5 g/L PPO
  - Overwhelming ^{14}C contamination from TMB ~200 kBq from atmospheric ^{14}C
  - High light yield >0.5 PE/keV

- Phase II
  - Apr 2015 – Present
  - 95% PC, 5% TMB
  - 1.4 g/L PPO
  - New TMB made from petroleum – much lower ^{14}C rate ~250 Bq (measured ^{14}C contamination of new TMB at the LLNL accelerator mass spectrometer to be below background)
  - High light yield > 0.5 PE/keV

LSV: The Scintillator Cocktail

- Pseudocumene (PC)
  - Primary scintillator
- Trimethyl borate (TMB)
  - Neutron capture agent
- PPO
  - Wavelength shifter

- Experience from Borexino
- Can share many of the same fluid handling plants
- Efficient liquid scintillator
- Have a source of petroleum-derived PC with very low ^{14}C contamination

LSV: The Scintillator Cocktail

- Pseudocumene (PC)
  - Primary scintillator
- Trimethyl borate (TMB)
  - Neutron capture agent
- PPO
  - Wavelength shifter

- Contains boron, which has 20% ^{10}B
- ^{10}B has **high thermal neutron capture cross section** (3837 b)
- Mixes well with PC
- 50% PC + 50% TMB cocktail has 85% of the light yield of a pure PC cocktail

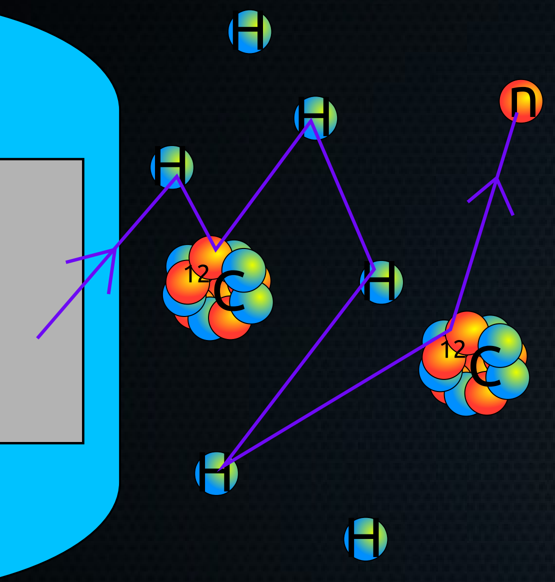
LSV: The Scintillator Cocktail

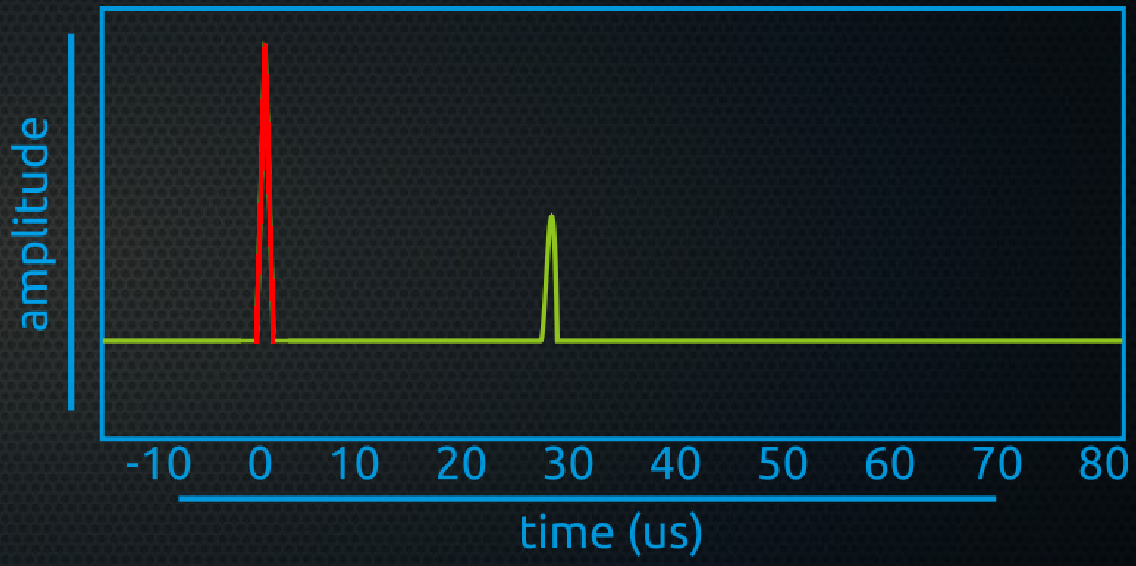
- Pseudocumene (PC)
  - Primary scintillator
- Trimethyl borate (TMB)
  - Neutron capture agent
- PPO
  - Wavelength shifter

- Absorption peak near PC emission
- Emission peak far from PC absorption
  → Long light attenuation length
- Shifts light near the peak PMT quantum efficiency
- Energy deposited in PC transferred non-radiatively to PPO
  - Very low concentrations
  - Scintillates faster and more efficiently than pure PC

Neutron Detection

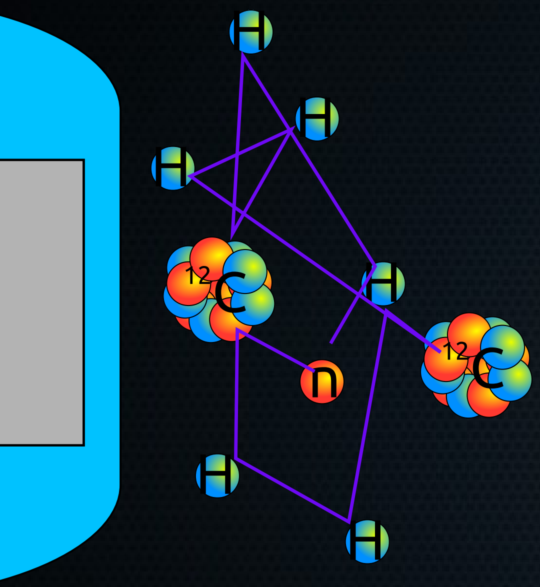
Neutron Detection: Prompt Signal

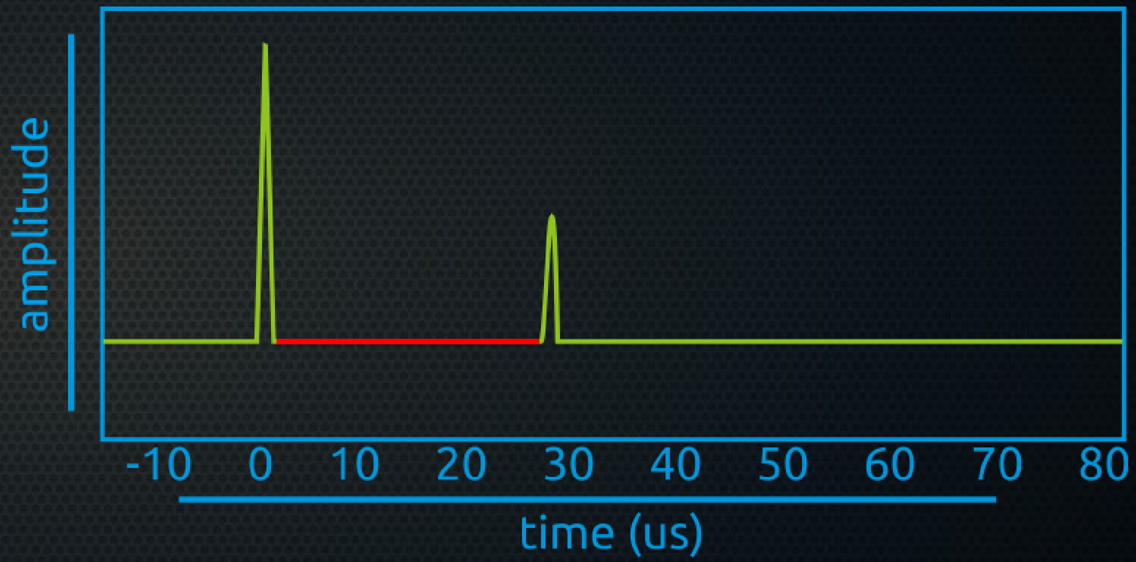




- Neutron thermalization
  - Very fast (< 100 ns)
  - Prompt time cut → low background
    → can cut with low threshold
  - Signal size depends on neutron energy

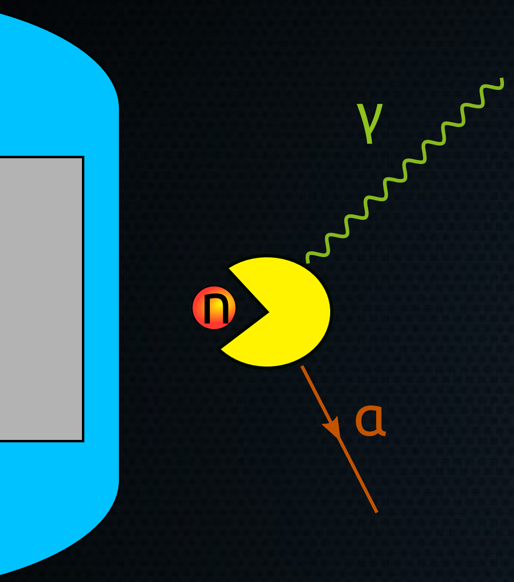
Neutron Detection: Quiet Time

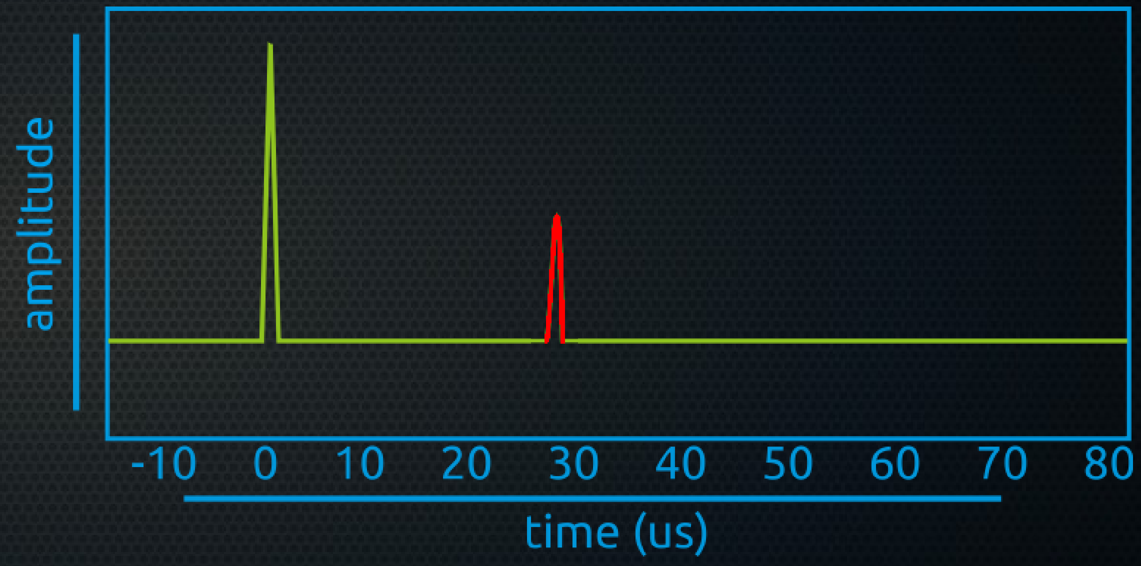




- Neutron random walk
  - No signal produced
  - Neutron random walks at thermal energies
  - At 50% TMB: τ = 2.2 us
  - At 5% TMB: τ = 22 us

Neutron Detection: Capture Signal





- Neutron capture
  - Neutron captures on
    - ^{10}B: $\sigma = 3837$ b
    - ^{1}H: $\sigma = 0.33$ b
      - Produces 2.2 MeV γ
  - At 50% TMB: 0.8% of captures on ^{1}H
  - At 5% TMB: 8% of captures on ^{1}H

Neutron Capture on ^{10}B

$$
\begin{aligned}
{}^{10}\mathrm{B} + n \rightarrow &\ {}^{7}\mathrm{Li}^{*}(839\ \mathrm{keV}) + \alpha\ (1471\ \mathrm{keV}) && (93.7\%) \\
&\ {}^{7}\mathrm{Li}^{*} \rightarrow {}^{7}\mathrm{Li} + \gamma\ (478\ \mathrm{keV}) && \\
\rightarrow &\ {}^{7}\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) && (6.4\%)
\end{aligned}
$$

Neutron Capture on ^{10}B

$$^{10}\mathrm{B} + n \rightarrow \ ^{7}\mathrm{Li}^{*}(839\ \mathrm{keV}) + \alpha\ (1471\ \mathrm{keV}) \qquad (93.7\%)$$

$$^{7}\mathrm{Li}^{*} \rightarrow ^{7}\mathrm{Li} + \gamma\ (478\ \mathrm{keV})$$

$$\rightarrow \ ^{7}\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) \qquad (6.4\%)$$

Relatively high energy, easy to see
But ~8% chance it will go back into cryostat unseen

Neutron Capture on ^{10}B

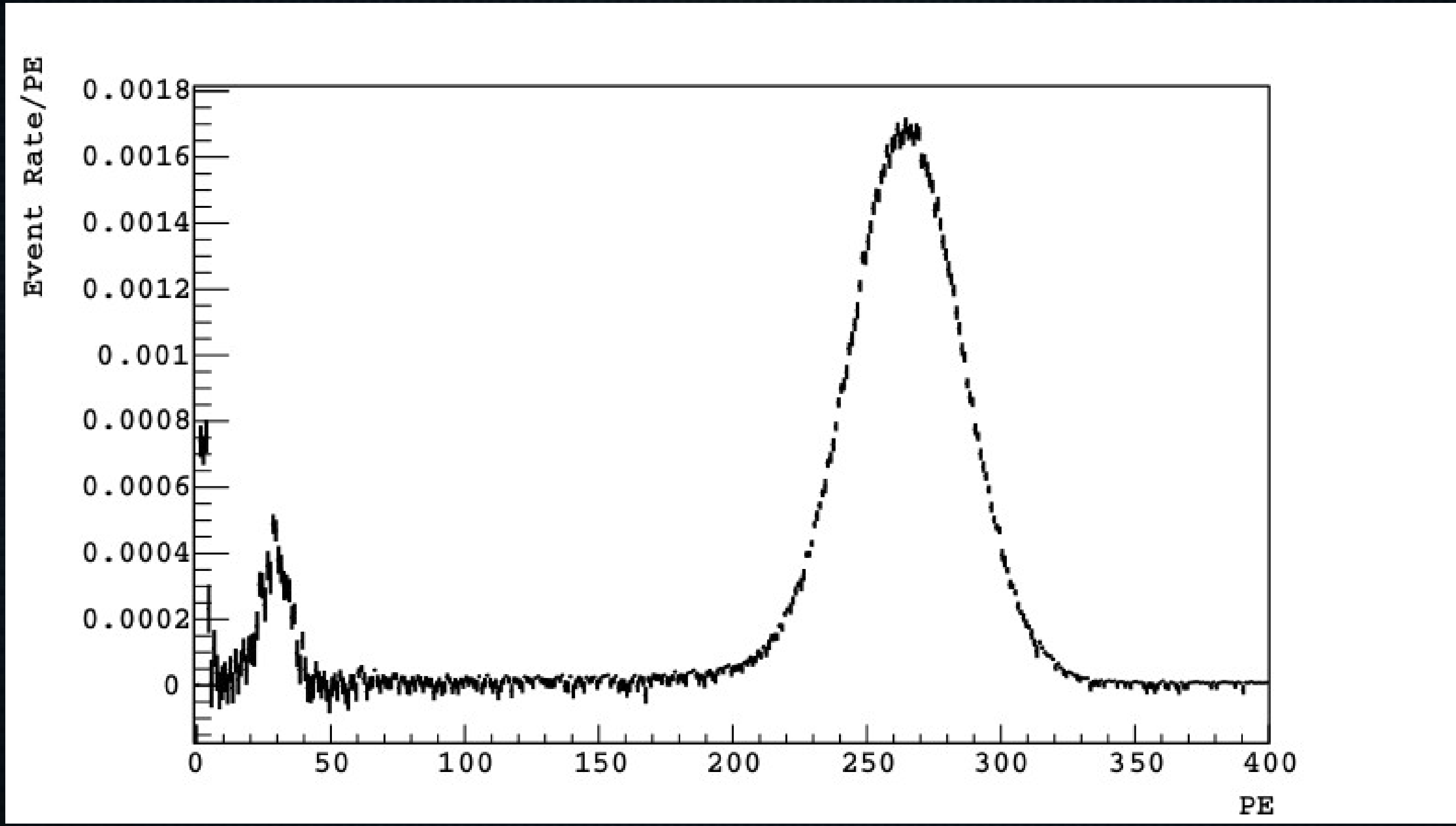
$$^{10}\mathrm{B} + n \rightarrow \ ^7\mathrm{Li}^*(839\ \mathrm{keV}) + \alpha\ (1471\ \mathrm{keV}) \qquad (93.7\%)$$

$$^7\mathrm{Li}^* \rightarrow ^7\mathrm{Li} + \gamma\ (478\ \mathrm{keV})$$

$$\rightarrow \ ^7\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) \qquad (6.4\%)$$

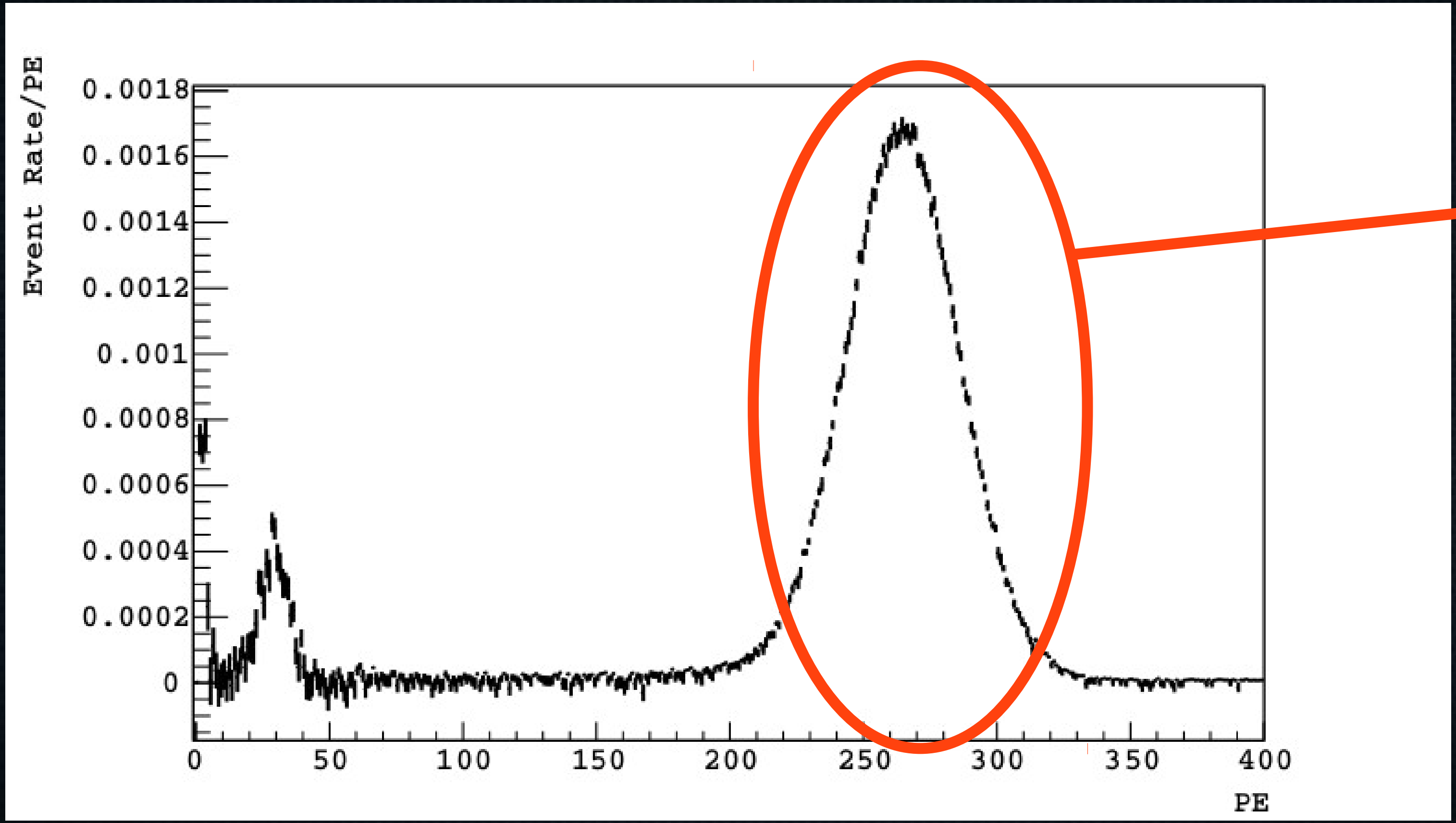
Highly quenched to a total signal equivalent to an electron energy of ~50-60 keVee
Will always deposit all energy into the scintillator
If we can reliably see these, we can see neutrons

Neutron Capture Signal



$^{241}Am^{9}Be$ Calibration Run

Neutron Capture Signal



$\gamma + \alpha + {}^{7}Li$

$^{241}Am^{9}Be$ Calibration Run

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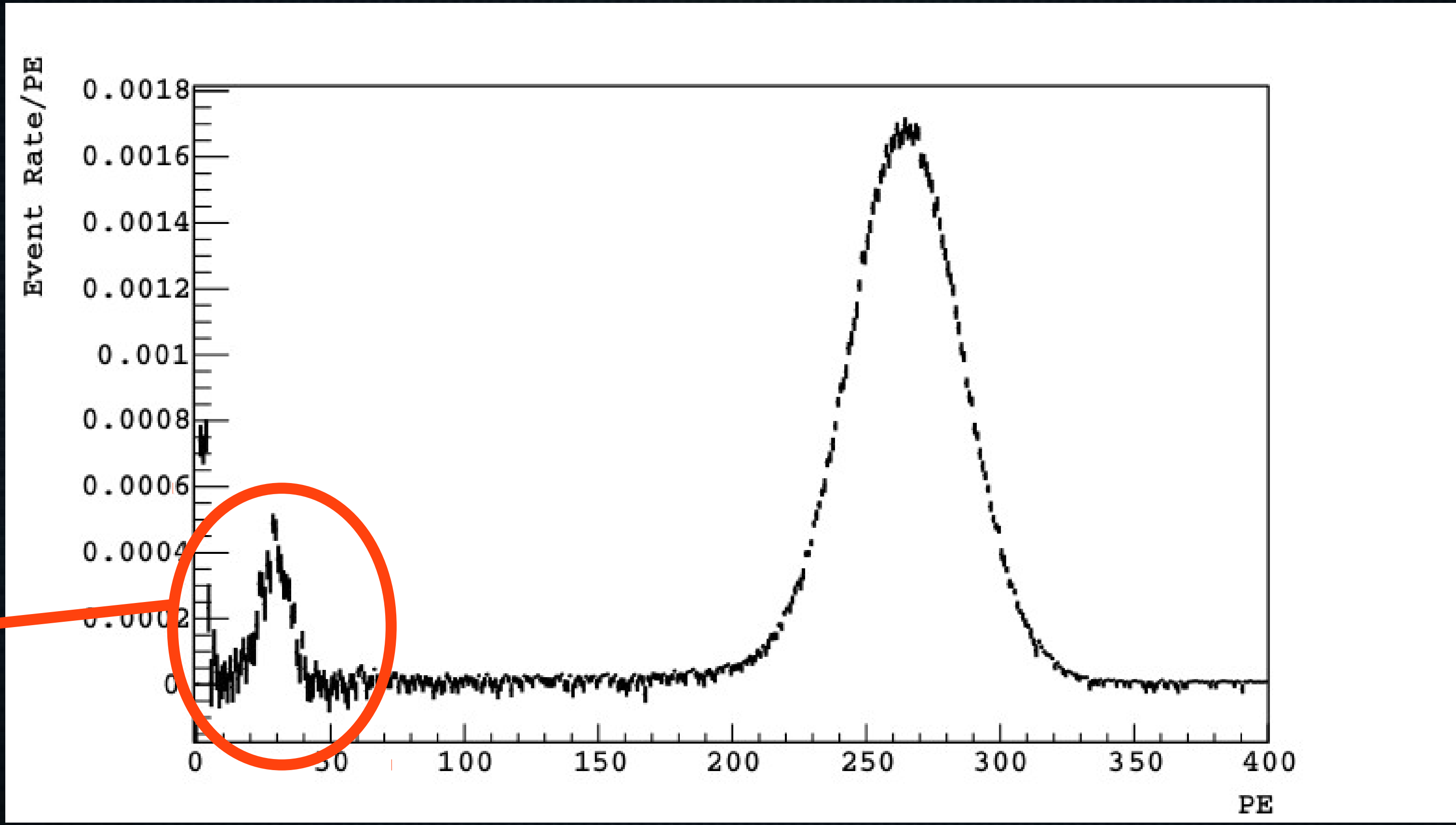


$\alpha + {}^{7}Li$

$^{241}Am^{9}Be$ Calibration Run

Neutron Vetoing Efficiency

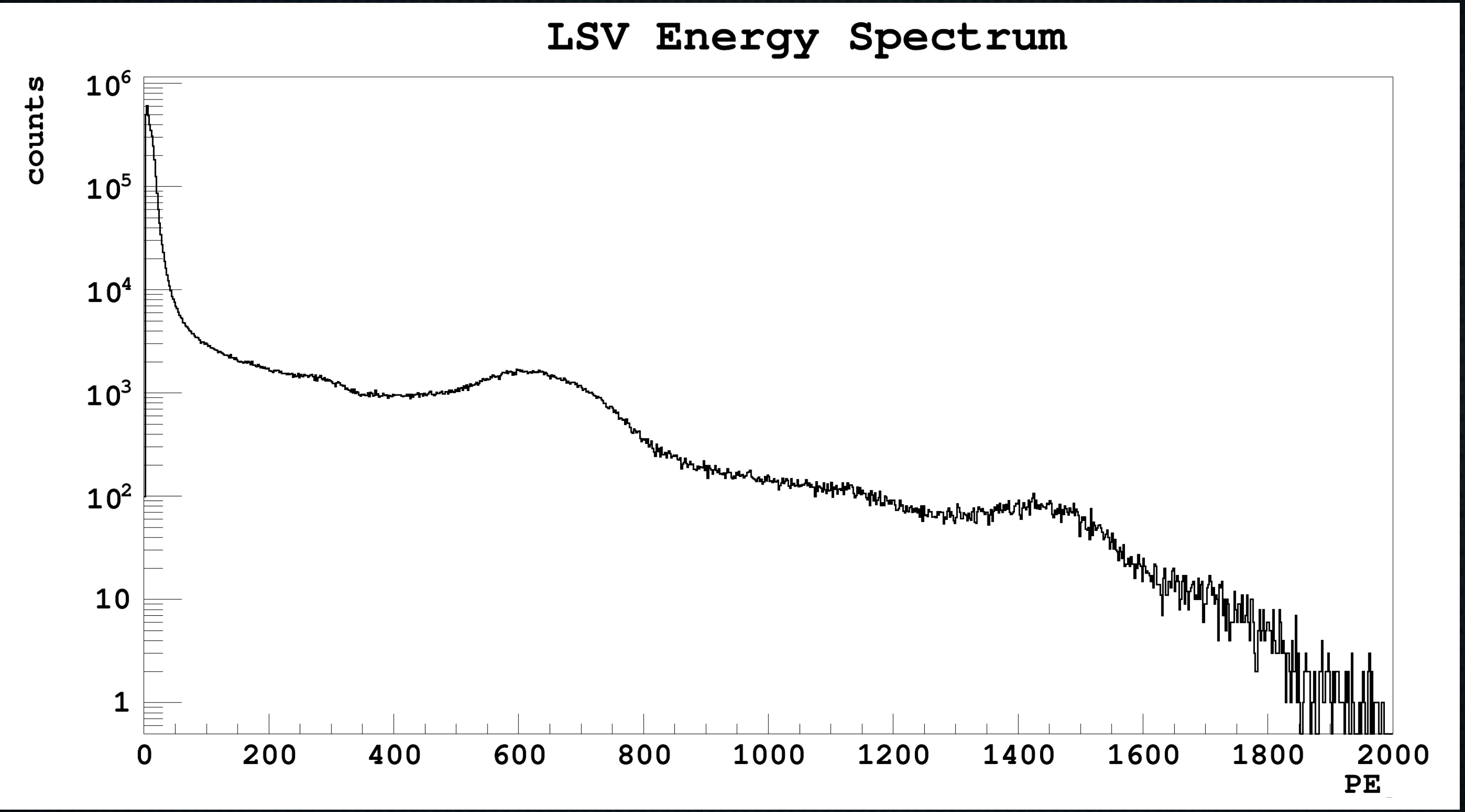
- Calibrations and simulations: vetoing efficiency from capture signal alone is > 99%
  - ~7.7% of neutrons capture on ^{1}H; 2.2 MeV γ lost ~8% of the time
  - ~0.05% of neutrons leave no signal in LSV at all
- Total efficiency is even larger due to thermalization signal
  - Low background → cut with 1 PE threshold (~0.9% acceptance loss)
  - Will evaluate using ^{241}Am^{13}C source

Conclusions

- We have developed a highly efficient neutron veto system for the DarkSide-50 experiment through the use of two nested outer detectors
- High light yield → high vetoing efficiency > 99%
- This is the first instrument to measure radiogenic neutron background and make a comparison with MC predictions
  - Allows us to validate background models in simulation
- A paper describing the outer detectors and their performance is being prepared and will be submitted for publication in the near future

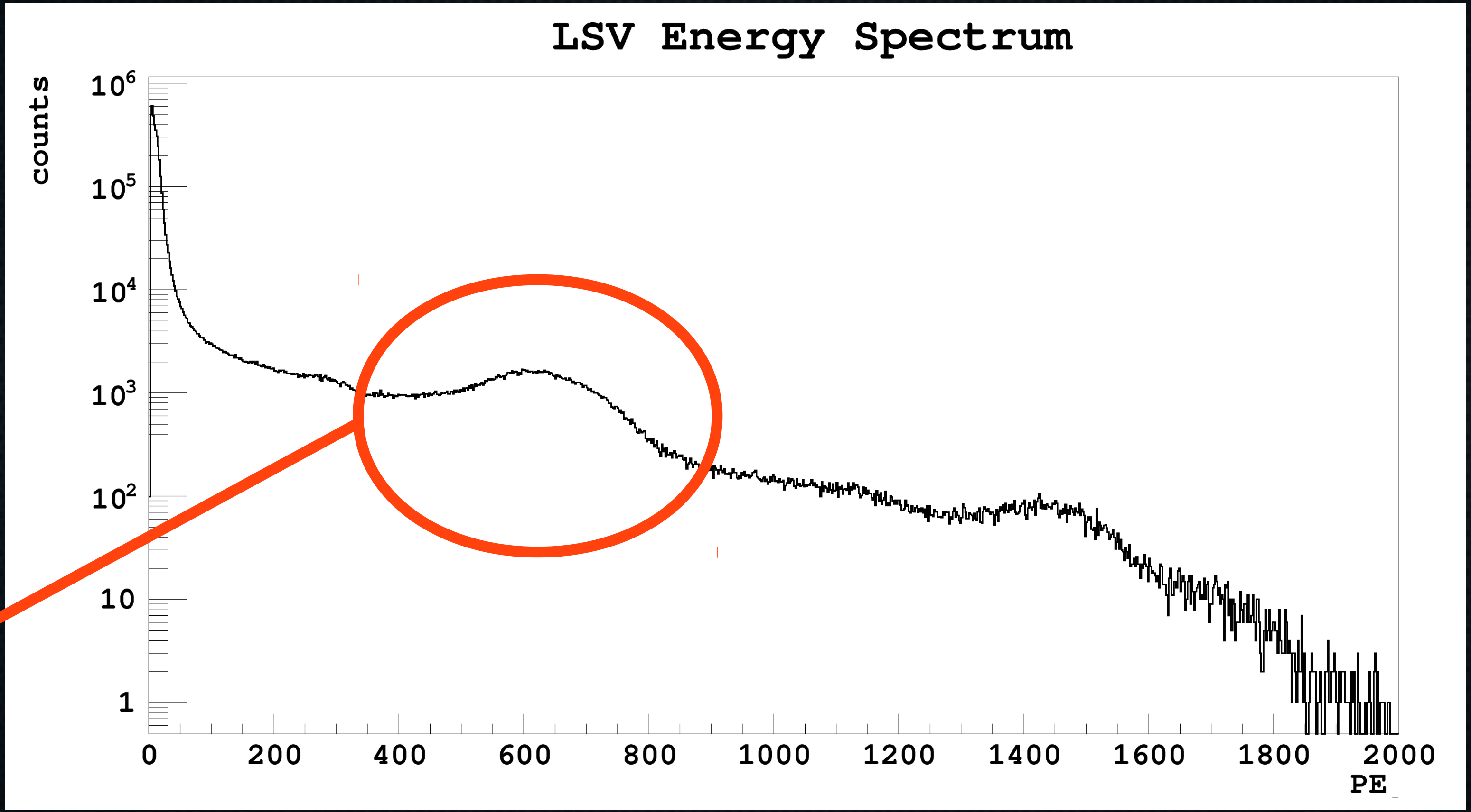

THE END
Veni, vidi, veto

Prompt LSV-TPC Coincidence



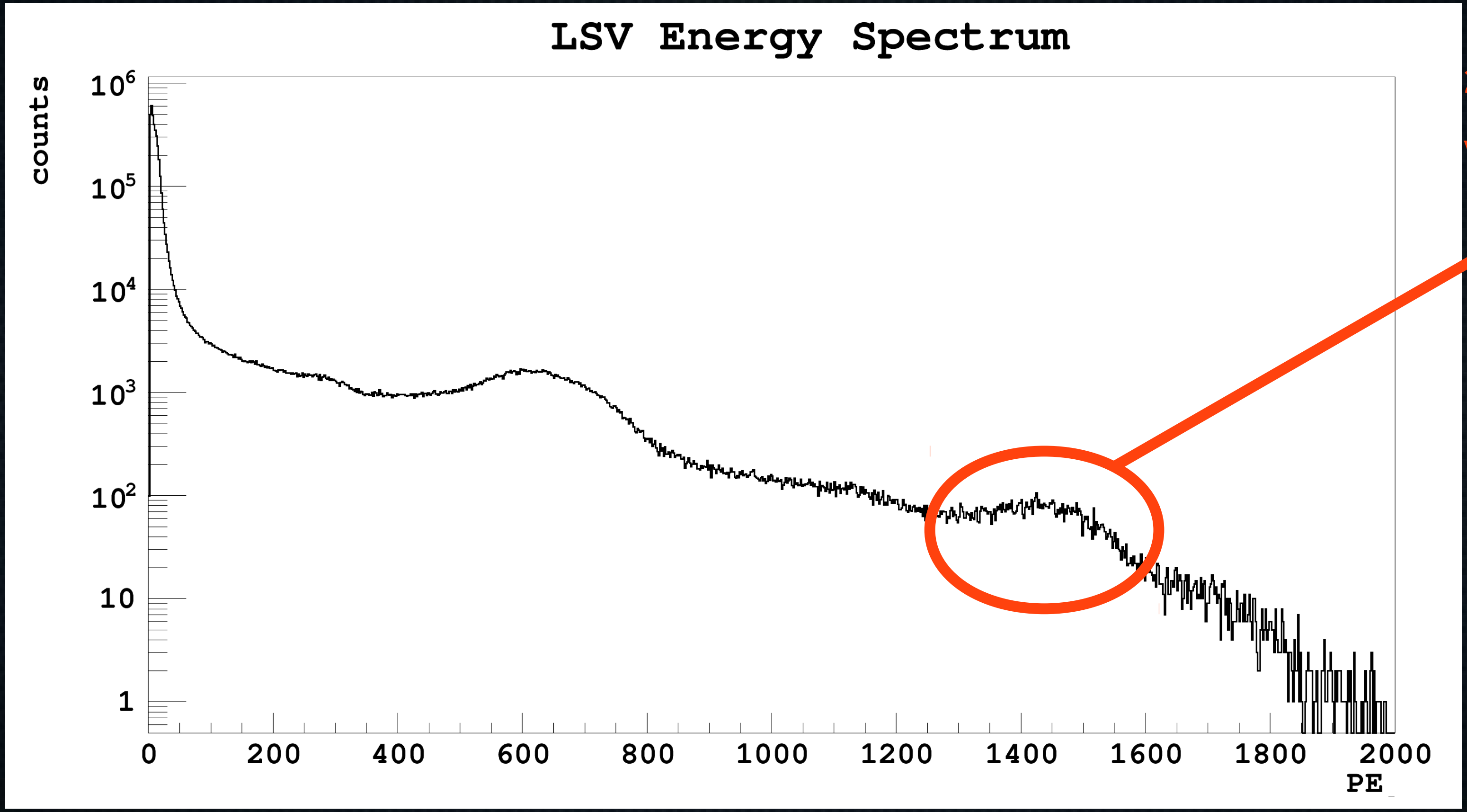
Note: these are mostly γ rays

Prompt LSV-TPC Coincidence



^{60}Co
γ(1.17 MeV)→ 0.52 PE/keV
γ(1.33 MeV)→ 0.54 PE/keV

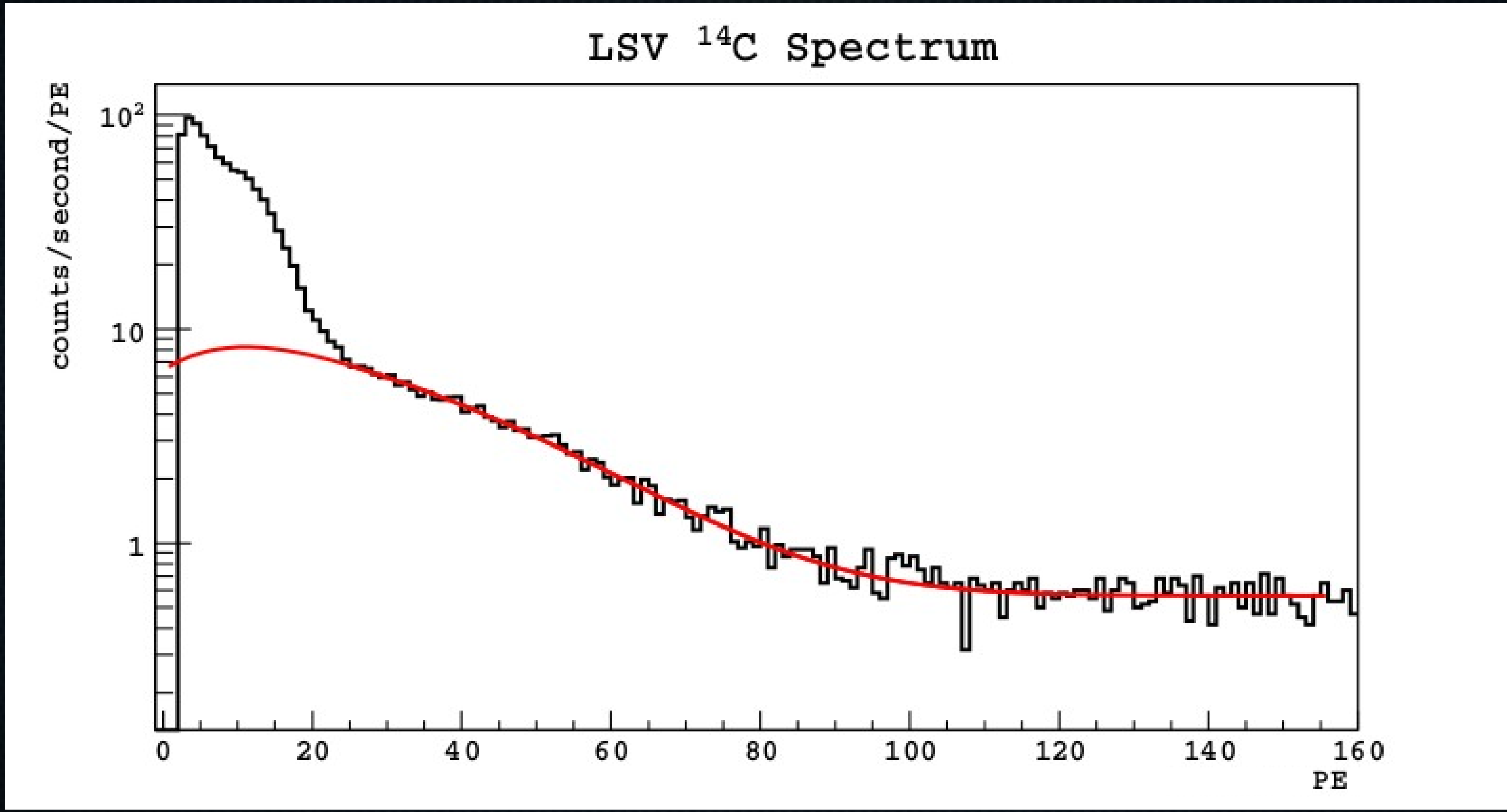
Prompt LSV-TPC Coincidence



^{208}Tl
γ(2.6 MeV)→ 0.55 PE/keV

14C Measurement

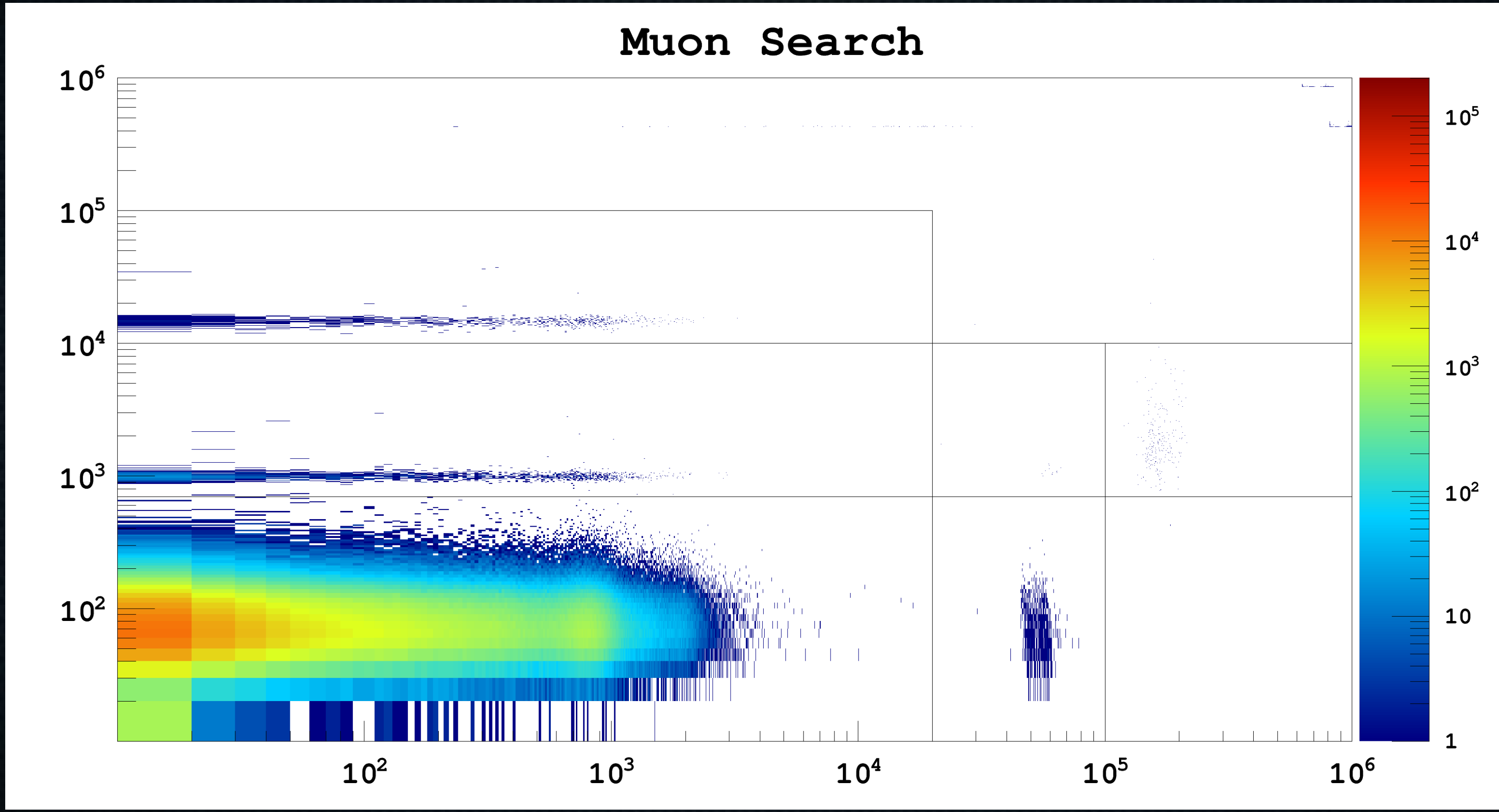
Phase II



Assumed:
- kB = 0.012 cm/MeV

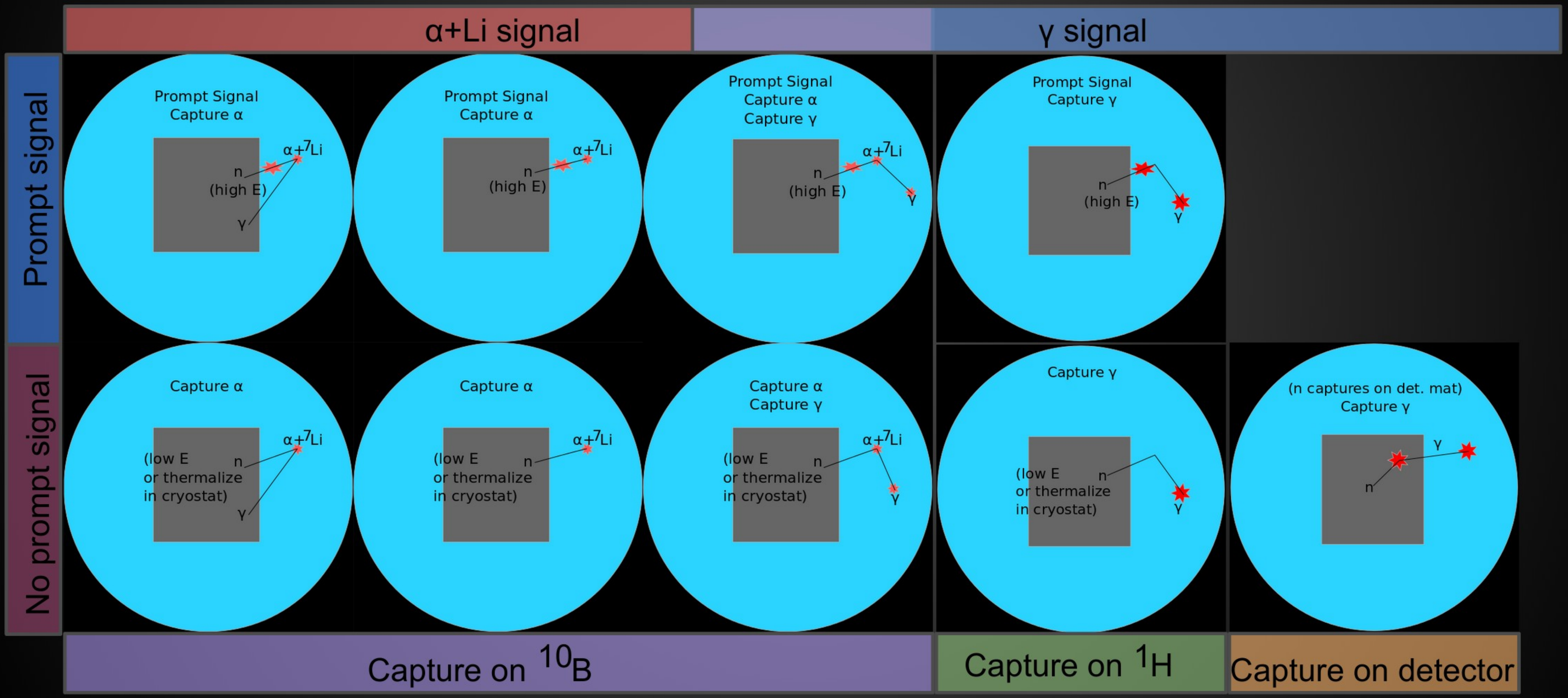
Measured:
- LY = 0.56(1) PE/keV
- Rate = 245±27 Bq

Muons

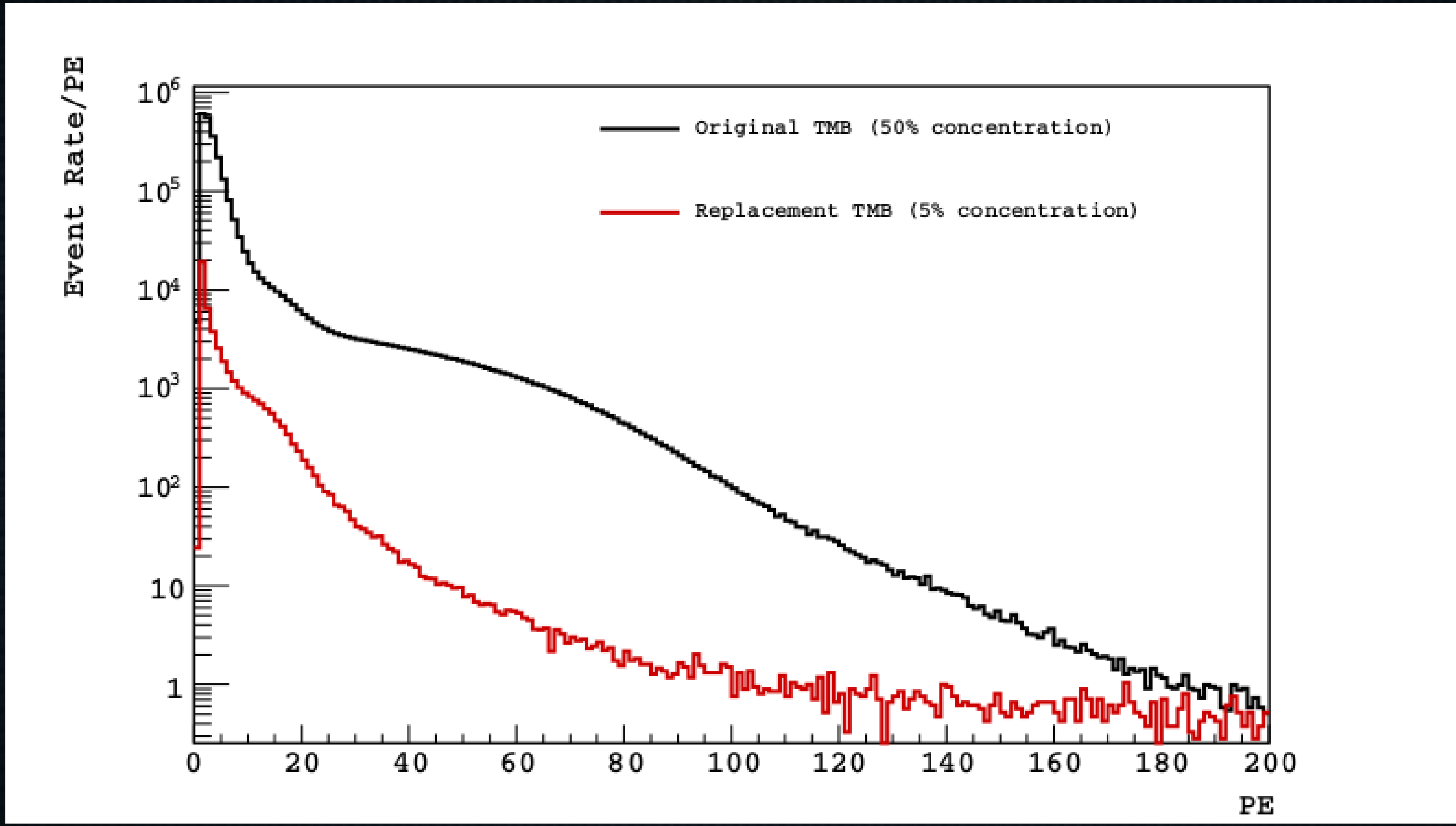


Muon Search
10^6
10^5
10^4
10^3
10^2
10^2
10^3
10^4
10^5
10^6
10^5
10^4
10^3
10^2
10
1

Detection Mechanisms



^{14}C Phase I vs Phase II



Phase I rate: ~200 kBq

Phase II rate: 245 Bq